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Lithofacies analysis of CMP at northern prospect of the Petrikov potash deposit (Belarus)

Analiza litofacjalna warstw ilasto-marglistych północnej części złoża soli potasowych Petrikow (Białoruś)

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Abstract

The results of lithofacies analysis of clay-marl package (CMP) at Northern Prospect of Petrikov potash deposit are discussed. The analysis has been undertaken to increment waterproof thickness. Lithofacies subdivision has been carried out with ArcGIS 10 software. The following three lithofacies have been defined: sulfate-carbonate-clay, sulfate-clay-carbonate, and clastic-carbonate-clay. An inclusion of gypsum-bearing sub-package of the CMP into the waterproof thickness, based on the lateral lithofacies variation of rocks, will allow pillar mining at the areas, where the mining is prohibited at present by local regulatory documents.

Key words: lithofacies analysis, Petrikov potash deposit, waterproof thickness, lithostratigraphy, ArcGIS.

Streszczenie

W pracy omówiono wyniki analizy litofacjalnej warstwy ilastomarglistej (WIM) północnej części Pietrykowskiego złoża soli potasowej na Białorusi przeprowadzonej w celu rozpoznania warstw nieprzepuszczalnych. Rejonizację litofacjalną wykonano za pomocą programu ArcGIS 10. Wyróżniono trzy litofacje: siarczanowo-węglanowo-ilastą, siarczanowo-ilasto-węglanową oraz klastyczno-węglanowo-ilastą. Włączenie do warstwy nieprzepuszczalnej subwarstwy gipsowej WIM, które oparto na lateralnej zmienności litolofacjalnej skał, w przyszłości pozwoli na eksploatację złoża systemem filarowym. Obecnie eksploatacja złoża jest zabroniona .

Słowa kluczowe: analiza litofacjalna, Pietrykowskie złoże soli potasowej, warstwa nieprzepuszczalna, ArcGIS.

Introduction

The areas, where the protective waterproof overburden is absent or its thickness is less than the required minimum, have been defined at Petrikov deposit in the result of drilling of two shaft boreholes (1k and 2k), of hydrogeological borehole 1d, as well as in the result of seismic survey. These areas are potentially dangerous in terms of possible discharge of aggressive water into underground workings. Lithofacies analysis allows justifying partial inclusion of the deposits of clay-marl package into the waterproof thickness in order to increment waterproof thickness within the area of Northern Prospect of Petrikov potash deposit (Figure 1).

Subject and methods of the study

The notion "lithofacies", used in this paper, has been proposed and developed by R. Moore, L. Sloss, E. Deppls, and W. Krumbein (Moore, 1949; Krumbein, Sloss, 1963; Sloss 1960). By lithofacies is implied peculiarities of lithological composition of rocks of stratigraphic unit at a certain place. Application of this particular definition is explained by practical reasons in oil and mining geology, in order to avoid confusions with genetic component. In 1970-s the American specialists had proposed graphical lithofacies method (Eduardo, 2007; Ratcliffe, Zaitlin, 2010), the principles of which, with modern adjustments in the field of geoinformational systems, have been used by the authors of this paper.

The authors modelled lithofacies maps, where distribution of rocks belonging to certain stratigraphic unit is shown. Stratigraphic units, matching the following criteria: consistent definition in the cross-section in geological documentation (field description, summary description, photodocumentation); relia-

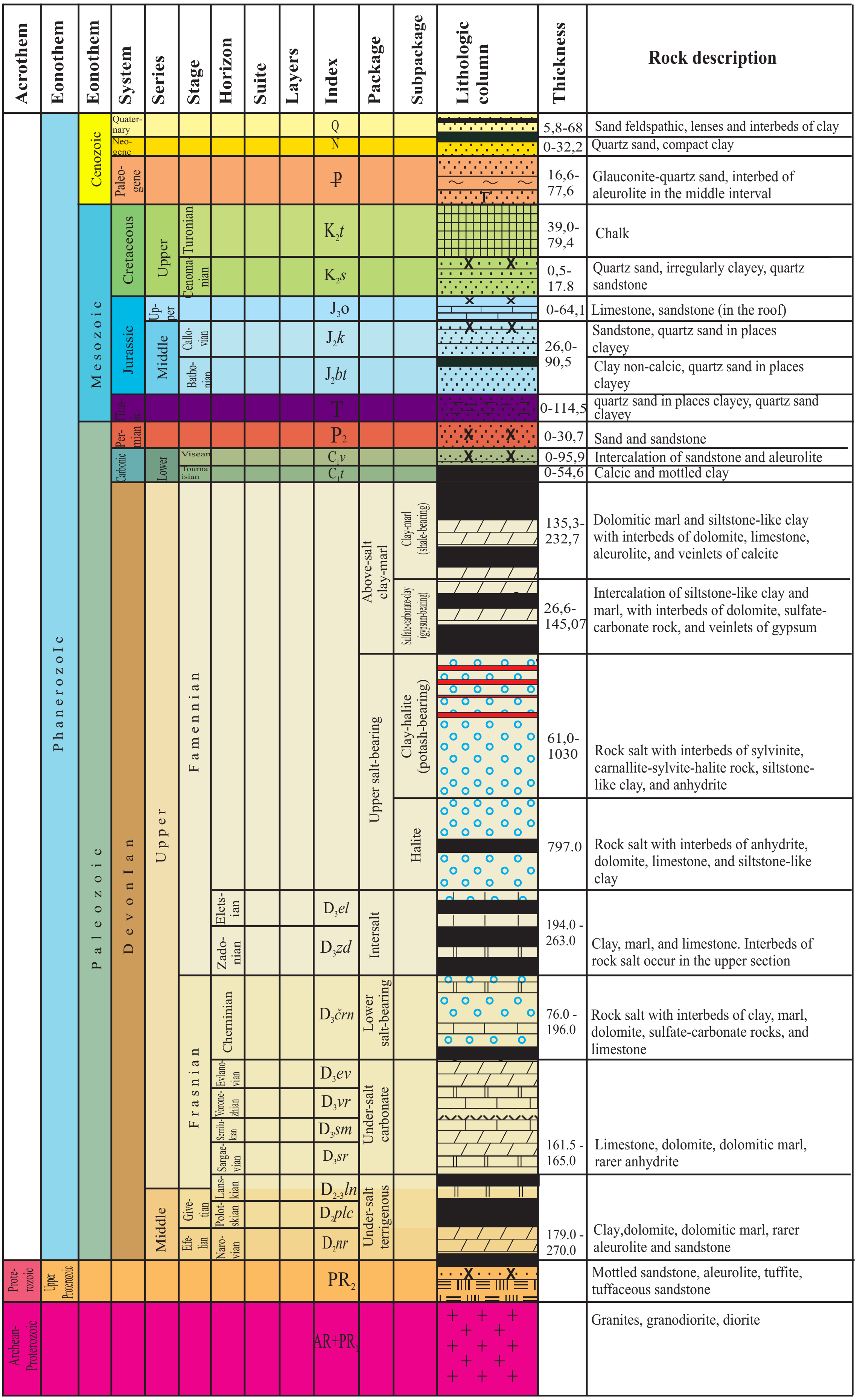

***Fig. 1**. Stratigraphic chart of Petrikov potash deposit (legend is in accordance with Color Code to the CCGM, 2005)*

Ryc. 1. Profil stratygraficzny Petrykowskiego złoża (Symbole według Color Code to the CCGM, 2005) ble concurrence with materials of borehole geophysical survey (first of all with gamma and resistivity logging). Isochronous units, including chronostratigraphic units of regional scale, and, for Petrikov deposit, suites of local scale, have not been used, because in most cases their definition has been based on the fossil flora and fauna. The authors have studied changes in lithofacies within basic stratigraphic units, i.e. lithostratons (lithostratigraphic units). Lithostratigraphic classification of CMP has simplified significantly from 1969 until 2016. The clay-marl package, by the features of forming rocks, is divided into two subpackagees: gypsum-bearing (sulfate-carbonate-clay) (CMP_2) and shale-bearing (clay-marl) (CMP_1).

Gypsum-bearing (sulfate-carbonate-clay) subpackage is formed by irregular alternation of claystone-like clays and marls with bands of dolomites, aleurolite, sandstones, and numerous multidirectional veinlets of fibrous gypsum of the thickness from 2-5 cm to 20 cm. The upper boundary of sulfate-carbonate-clay subpackage is conventionally drawn along the interval of disappearance of transverse veinlets of fibrous gypsum in the cross-section. The nests and separate crystals of rock salt rarely occur at the base of the subpackage.

In general, the rocks of gypsum-bearing subpackage are noted for intensive fracturing. The fractures are filled with gypsum and/or calcite. Brecciation, folding, and fragmentation of rocks, as well as numerous teared-off slip planes are found in certain intervals.

The thickness of gypsum-bearing subpackage within the deposit is inconsistent, and varies from 25 to 100 m. By age, the deposits of gypsum-bearing subpackage belong to Liuban layers and upper part of Ostrovets layers of Streshin horizon of Upper Devonian.

Clay-marl (shale-bearing) subpackage accomplishes the section of the above-salt clay-marl package of the Upper Devonian. It thickness within the deposit ranges from 30-40 m within domes and anticlines to 100-200 m within syncline zones.

The depth of roof of shale-bearing subpackage within the deposit, depending on structural position, varies from 204.7 to 535.5 m.

The rocks of shale-bearing subpackage consist of dolomite marls, claystone-like clays with bands of aleurolites and dolomites, with veinlets and nests of calcite. The thickness of bands ranges from 5 cm to 1-7 m. Layers of sandstone with quartz-lime cement occur sometimes. The rocks of shale-bearing subpackage are frequently fractured, and sometimes folded. The characteristic feature is the occurrence of two seams (bands) of oil shales and sapropelic marl. The lower seam (band) consists of 4-6 interbeds of kerogen-containing rocks of the thickness ranging from 0.15 to 2.5 m. The interval between those interbeds is 1-5 m in average. In total, the thickness of the lower seam varies from 15 to 25 m. Interbeds of stromatolithic limestone of the thickness 5-30 cm occur in the lower seam (band) with layers of oil shales and sapropelic marl, in the interval 20 m above. The upper shale-bearing seam (band) occurs 55-80 m above the lower seam in some boreholes. Up to three interbeds of sapropelic marl are found in that upper seam.

The main subject of study has been gypsum-bearing (sulfate-carbonate-clay) subpackage of clay-marl package.

The maps of isoconcentrates of clay, carbonate, sulfate, and clastic rocks in the gypsum-bearing subpackage and CMP have been developed in geoinformation software ArcGIS (ESRI Inc., USA) using Krige method (kriging). The maps of isopachs of those rock varieties have also been developed within the boundaries of estimation of reserves of A, B, C_1 and C_2 categories at Northern Prospect of Petrikov potash deposit.

The lithofacies ternary graphs have been plotted in the results of computer data processing. The graphs have been used to reveal relationships between several variables (in this paper between sulfate-carbonate, clay and clastic material), when three of the variables represent, for example, the components of certain lithofacies (Figure 2). Relationships between three groups of rocks are expressed in percent, at that the total thickness of a straton is taken as 100%.

The corners of triangle refer to 100% of a content of each of the three components, and subtending the corner sides refer to the absence of corresponding component.

The boundary points have been defined using ternary graphs. These points were used to define the following lithofacies in the cross-section of gypsum-bearing CMP subpackage: sulfate-carbonate-clay, sulfate-clay-carbonate, and clastic- carbonate-clay. (Table 1).

The layer of lithofacies have been created automatically in the geoinformational system ArcGIS (Figure 3). Computed

Table 1. *The mask of determination of lithofacies in gypsum-bearing subpackage of CMP*

Tabela 1. Maska wyznaczania litofacji w gipsonośnej subwarstwie CMP

Lithofacies	**Material, %**		
	Sulfate-carbonate	**Clayey**	**Clastic**
Sulfate-carbonate-clay	0.0 – 30.0	70 – 100	0.0 – 2.5
Sulfate-clay-carbonate	30.0 – 60.0	37.5 – 70	0,0 – 2.5
Clastic- carbonate-clay	0.0 – 60.0	37.5 – 100	2.5 – 10

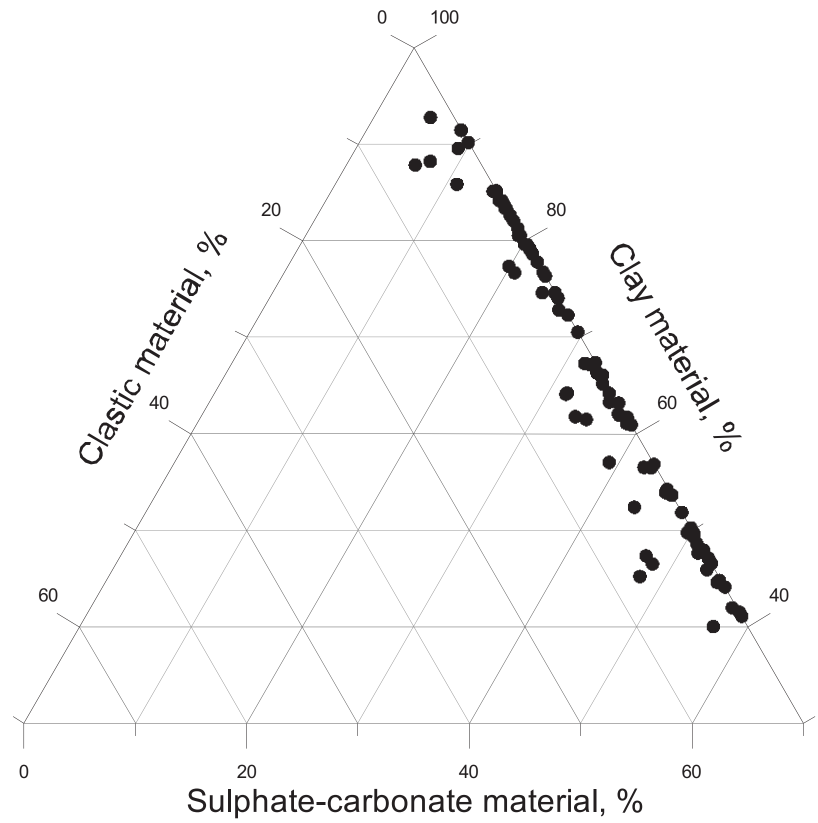

***Fig. 2**. Litofacies ternary graph for gypsum-bearing subpackage of CMP*
Ryc. 2. Wykres litofacjalny trójskładnikowy subwarstwy gipsowej WIM

with Krige method (kriging) interpolational GRID-models of isoconcentrates of clayey, clastic, carbonate and sulfate rocks have been re-classified separately according the mask of determination of lithofacies (Table 1).

The merger of all cells of the each GRID-model, associated with certain lithofacies, and assignment them with a unique code took place in the process of re-classification. Re-classified models of percent content of clayey, clastic, carbonate and sulfate rocks in gypsum-bearing subpackage were then converted into separate vector layers of the polygonal geometry. The unique code that reflects reference of each polygon of the layer to certain lithofacies is listed in the attributes tables of vector layers. Finally the intersection of three layers of polygonal vectors, resulting from re-classification of percentage of clayey, clastic, carbonate and sulfate rocks, has been done. The vector layer of lithofacies was formed in the result of that intersection.

The results of study

Three lithofacies have been defined in the cross-section of gypsum-bearing subpackage of CMP: sulfate-carbonate-clay, sulfate-clay-carbonate, and clastic- carbonate-clay (Figure 4).

Sulfate-carbonate-clay lithofacies consists of dark-grey, compact, laminated marl and dark-grey, in places fractured, claystone-like clays with layers of carbonate-sulfate-clay rocks, dolomite, dolomitic limestone, and with veinlets of gypsum and gypsum-selenite in the upper part of the cross-section. The lithofacies occurs evenly within the boundaries of estimation of reserves of A, B, C_1 and C_2 categories at Northern Prospect of Petrikov potash deposit, and occupies 42.2% of the area. The thickness of gypsum-bearing supackage there varies from 52.6 to 120.0 m.

Sulfate-clay-carbonate lithofacies is represented by grey, compact, laminated marl with interbeds of sulfate-carbonate-clay rock, clay-calcic-anhydrite and calcic-anhydrite rock, as well as of dolomitic claystone-like clays with veinlets of gypsum in the upper part of the cross-section. The lithofacies occurs evenly within the boundaries of estimation of reserves of A, B, C_1 and C_2 categories at Northern Prospect of Petrikov potash deposit (44.8% of the area). The thickness of gypsum-bearing supackage there varies from 56.0 m (borehole 373) to 145.07 m (borehole 312).

Clastic-carbonate-clay lithofacies is formed predominantly by calcic, in places fractured claystone-like clays with interbeds of dolomites, aleurolite, sandstone, by sulfite-carbonate rock with veinlets of gypsum, and by dark-grey, fractured, in some areas aleuritic marl with interbeds of clayey dolomite and aleurolite. The lithofacies occurs locally, in the area of boreholes 247, 252, 263, 283, 292, 319, 323, 324, 355, 356, 1050g, 324g, 364d (12.8 % of the total area). The thickness of gypsum-bearing supackage there varies from 26.6 m (borehole 292) to 120,4 m (borehole 247).

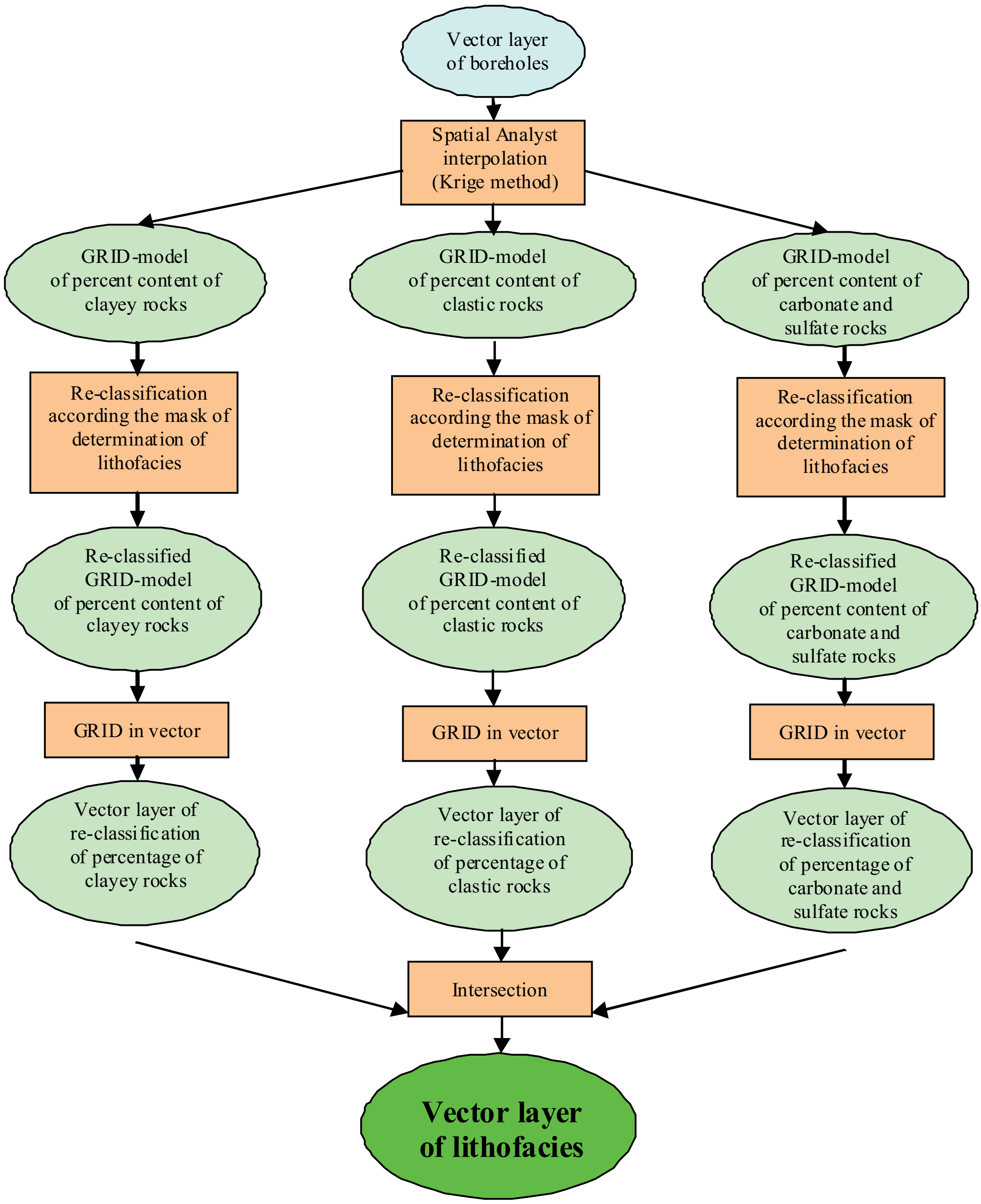

***Fig. 3**. Algorithm of definition of lithofacies within the study area by means of GIS*

Ryc. 3. Algorytm wyróżnienia litofacje w granicach obiektu badań z wykorzystaniem programu systemy informacji geograficznej

Regular increase in the thickness of seismopacket CMG_1-I is noted within the boundaries of estimation of reserves of A and B categories, in the areas of occurrence of clastic-carbonate-clay lithofacies. The lithofacies occurs there locally, in the area of boreholes 355, 263, 364, 364д. In the same area an increase in the thickness of seismopacket CMG_1-I from 40 m to 60 m takes place (boreholes 263, 355, 362, 386).

Conclusions

The areas of occurrence of sulfate-carbonate-clay and sulfate-clay-carbonate lithofacies have been delimited in the result of lithofacies analysis. The accretion of gypsum-bearing subpackage of clay-marl package is possible within those areas at the Northern Prospect of Petrikov potash deposit. The accretion of waterproof thickness at the expense of gypsum-bearing CMP subpackage in the area of occurrence of clastic-carbonate-clay lithofacies requires further investigations.

An inclusion of gypsum-bearing CMP subpackage into waterproof thickness, taking into account lateral lithologic--facial variability of rocks would enable pillar mining at the areas, where the mining is prohibited at present by "Temporary instructions on protection of the mine from flooding

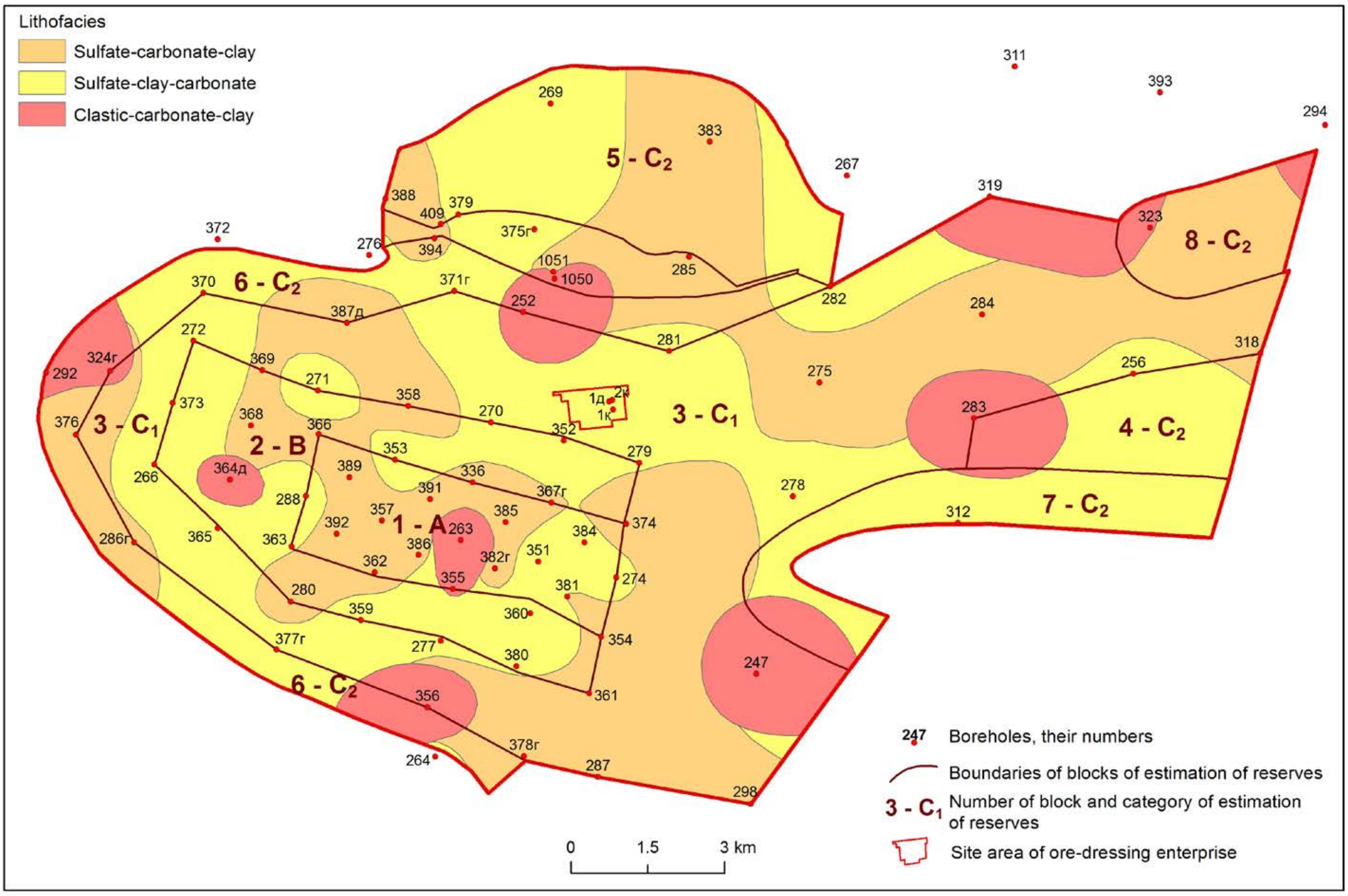

***Fig. 4**. Lithologic-facial zoning of gypsum-bearing subpackage of CMP within the area of reserves estimation of IV-n potash horizon (Northern prospect of Petrikov potash deposit)*

Ryc. 4. Rejonowanie litofacjalne subwarstwy gipsowej WIM w granicach obliczenia zasobów pozioma IV-p (Północna część Petrykowskiego złoża soli potasowej)

under the conditions of Petrikov potash deposit with unstudied character of rocks and surface displacement process". Due to such an inclusion the areas of mining and reserves by A+B+C_1 categories, suitable for pillar mining, will increase by 23%.

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